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Influence of Ambient Temperature on Tailpipe Emissions from 1984-1987 Model Year Light-Duty Gasoline Motor Vehicles

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16. ABSTRACT

Motor vehicle emissions are sensitive to a number of variables including ambient temperature, driving schedule (speed vs time), and fuel composition. Hydrocarbon, aldehyde, carbon monoxide, and oxides of nitrogen emissions were examined with nine recent technology 4-cylinder gasoline motor vehicles at 70°F, 40°F, and 20°F. About 200 hydrocarbon and 12 aldehyde compounds were included in the organic emissions characterization. Two fuels and two driving schedules were used. Typically, hydrocarbon and carbon monoxide emissions were significantly increased by reduced ambient temperature. Oxides of nitrogen emissions also increased, but to a lesser extent. There were no predictable formaldehyde emissions trends with temperature. Paraffinic and aromatic hydrocarbon emission fractions were sensitive to fuel composition, but the olefinic emission fraction (dominated by ethylene and propylene) was not. With low temperature cold start tests, preceding transient driving with a 5 minute engine idle resulted in reduced carbon monoxide emission rates and elevated oxides of nitrogen emission rates. Hydrocarbon emission rates were not predictably sensitive to the preliminary idle.

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THE INFLUENCE OF AMBIENT TEMPERATURE ON TAILPIPE EMISSIONS FROM 1984–1987 MODEL YEAR LIGHT-DUTY GASOLINE MOTOR VEHICLES

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Abstract—Motor vehicle emissions are sensitive to a number of variables including ambient temperature, driving schedule (speed vs time) and fuel composition. Hydrocarbon (HC), aldehyde, CO and oxides of nitrogen (NO_x) emissions were examined with nine recent technology 4-cylinder gasoline motor vehicles at 21.1°C (70°F), 4.4°C (40°F), and −6.7°C (20°F). About 200 HC and 12 aldehyde compounds were included in the organic emissions characterization. Two fuels and two driving schedules were used. Typically, HC and CO emissions were significantly increased by reduced ambient temperature. NO_x emissions also increased, but to a lesser extent. There were no predictable formaldehyde emissions trend with temperature. Paraffins and aromatic HC emission fractions were sensitive to fuel composition, but the olefinic emission fraction (dominated by ethylene and propylene) was not. With low temperature cold start tests, preceding driving with a 5 min engine idle resulted in reduced CO emission rates and elevated NO_x emission rates. HC emission rates were not predictably sensitive to the preliminary idle.

Key word index: Mobile source emissions, temperature effects, hydrocarbon, carbon monoxide, oxides of nitrogen emissions.

INTRODUCTION

Motor vehicle emissions are sensitive to a number of variables including speed, load, ambient temperature and fuel composition. Several investigators have reported that total hydrocarbon (THC) and carbon monoxide (CO) emissions are elevated when vehicles are operated at reduced ambient temperatures (Ashby *et al.*, 1974; Eccleston and Hurn, 1978; Ostrouchov, 1979; Spindt and Hutchins, 1979; Marshall and Eccleston, 1980; Braddock, 1981; Austin *et al.*, 1983; Ostrouchov, 1987), and the Department of Transportation has estimated that nearly 2/3 of all vehicle-miles-travelled (VMT) in the U.S. are at temperatures below that examined in federal emissions certification 20–30°C (68–86°F) (DOT, 1974). Motor vehicle HC emissions are regulated because of involvement in photochemical processes that result in the formation of O_3 and other oxidants of public health concern. EPA has established a National Ambient Air Quality Standard (NAAQS) for O_3 at 0.12 ppm (volume) (1 h average). Most exceedances of this standard occur during the summer when emissions and atmospheric conditions favor the formation of O_3, thus the use of summer driving simulations in motor vehicle emissions certification. There is also a NAAQS for CO at 9 ppm (volume) (8 h average). Many of the exceedances of this standard occur during winter and there is growing concern that winter exposure to motor vehicle organic emissions could potentially pose a threat to public health. Formaldehyde, benzene and 1,3-butadiene have been identified as compounds emitted from motor vehicles with potential carcinogenic concern (Carey, 1987).

This report is among a series in which the EPA Office of Research and Development has examined the sensitivity of motor vehicle emissions to changes in ambient temperature (Braddock, 1981, 1982; Gabele *et al.*, 1986; Baugh *et al.*, 1987; Snow *et al.*, 1987). Emissions from nine recent technology gasoline fueled passenger cars are examined with varied ambient temperatures, fuels and driving schedules. THC, CO, NO_x, detailed HC (about 200 compounds) and detailed aldehyde (about 12 compounds) emissions are characterized. This data will expand our understanding of the rate and composition of emissions from recent model gasoline automobiles as necessary to project the potential impact of these sources on urban O_3, and to estimate seasonal exposure to motor vehicle emissions. MOBILE 3, the EPA model used to

project fleet average THC, CO and NO_x emission factors, uses algorithms to adjust baseline values (obtained with federal certification test procedures) to conditions (temperature, speed, etc.) representative of the area being modeled. The data on which these algorithms are based will also be expanded.

EXPERIMENTAL

Test procedures

The primary objective of this program was to determine the sensitivity of late model light-duty gasoline fueled motor vehicle tailpipe emissions to changes in ambient temperature. Typically, vehicle-to-vehicle emissions variability exceeds individual vehicle run-to-run variability, and therefore the test protocol involved a maximum number of different vehicles with a minimum number of test repetitions with each vehicle. Duplicate tests were planned for every fifth test vehicle, and single tests with all others at each driving scenario examined. Test were conducted at 21.1°C (70°F), 4.4°C (40°F) and −6.7°C (20°F).

Fuel characteristics must be varied seasonally for optimum vehicle driveability. For example, winter fuels typically have higher volatility than summer fuels. To permit resolution of fuel effects from temperature effects, the 21.1°C (70°F) tests were conducted with a summer grade unleaded gasoline, 4.4°C (40°C) tests with both the summer grade gasoline and a winter grade unleaded gasoline and −6.7°C (20°F) tests with the winter grade gasoline. Two driving schedules were used: the standard Urban Dynamometer Driving Schedule (UDDS) of the Federal Test Procedure (FTP) used for light-duty vehicle emissions certification (U.S. Code of Federal Regulations, 1983), and a modified FTP (MFTP) where the UDDS was preceded by a 5 min idle period. The MFTP was used to determine if the practice of idling an engine prior to driving, as is common to warm-up and defrost a vehicle prior to operation during winter months, influences emissions. The MFTP emission rates were calculated by adding the idle emission mass to test phase 1 and performing FTP calculations as normal. A typical vehicle test schedule is given in Table 1.

Table 1. Test schedule

	First week	Second week
Sunday	—	Prep vehicle
Monday	Pick-up vehicle and prep QA-QC	FTP 4.4°C (WG)
Tuesday	21.1°C FTP (SG)	MFTP 4.4°C (WG)
Wednesday	4.4°C FTP (SG)	FTP −6.7°C (WG)
Thursday	4.4°C MFTP (SG)	MFTP −6.7°C (WG)
Friday	Change fuel QA-QC retest if needed	Retests, return vehicle, pick-up next test vehicle if available

Note: (SG) with summer grade fuel, (WG) with winter grade fuel.

Table 2. Vehicles tested

Vehicle	Cyl.	Veh. (km)	Disp. (ℓ)	Fuel system	Emission system
1987 Toyota Camry	4	4448	2.0	FI	EGR/TWC/CL/OTR
1986 GM Grand Am	4	17,353	2.5	FI	BPEGR/PRC
1986 Ford Mustang	4	48,564	2.3	1 bl Carb.	EGR/EGS/PMP/TWC/OC/CL
1984 GM Cavalier	4	99,214	2.0	T.B. FI	BPEGR/ORC/Catalyst pair/TWC/CL
1986 Chrysler Omni	4	31,778	2.2	2 bl Carb.	EGR/PMP/TWC/CL
1987 Nissan Sentra	4	6753	1.6	2 bl Carb.	EGR/ECC/PMP/TWC + OC/CL
1985 Honda Accord	4	85,914	1.8	FI	EGR/AIS/TWC
1987 Toyota Corolla	4	16,449	1.6	2 bl Carb.	EGR/AS/O_2S/TWC/CL
1987 Dodge Caravelle	4	8766	2.2	FI	EGR/PLS/OC/CL

Note:

EGR	Exhaust gas recirculation.
BPEGR	Back pressure EGR.
ORC	Oxidation-reduction catalyst.
TWC	Three way catalyst.
PMP	Air pump.
OC	Oxidation catalyst.
Air	Air injection reactor.
CL	Closed loop.
AS	Air switching.
O_2S	Oxygen sensor.
PLS	Pulse air.
AIS	Air injection system.

Catalyst Pair – Catalyst pulse air injection reaction system.

Vehicles tested

The vehicle test fleet is summarized in Table 2. All were recent technology high sales volume 4-cylinder engine, domestic and foreign passenger cars obtained from the local (Research Triangle, N.C.) consumer fleet. The vehicles were randomly selected from public responses to newspaper advertisements soliciting vehicles for emissions testing. Mileage accumulation ranged from about 4450 km to 99,200 km. Five of the vehicles were fuel injected and four were carburetted. A follow-on study planned for completion during the fall of 1988 will examine emissions from larger displacement engines.

Test procedures

Vehicles were prepared for each emissions test by operating on the test fuel of interest over a UDDS transient driving schedule, followed by an overnight soak at the next day's test temperature (21.1°C, 4.4°C or −6.7°C). As indicated in Table 1, the complete test schedule required 2 calendar weeks per vehicle (4 weeks when duplicate tests were completed). The emission test sequence included each of 3 FTP phases: cold transient, stabilized and hot transient; the stabilized and hot transient phases separated by a 10 min, engine off soak period. Cooling air was provided by a 467 m^3 min^{-1} fan placed 0.6 m in front of the test vehicle with the hood raised.

Fuels used

As previously indicated both summer grade (SG) and winter grade (WG) unleaded gasolines were used in this study. Both were commercial fuels with specifications as provided in Table 3. Figure 1 provides HC compositional descriptions of each fuel. The Motor Vehicle Manufacturers Association (MVMA) periodically publishes national average marketed fuel characteristics. During the summer of 1986, regular unleaded gasoline averaged 71.7 kPa, 59.8% paraffin, 10.6% olefin, 29.5% aromatic hydrocarbon, and during the winter of 1986/87, 93.1 kPa, and 62.1% paraffin, 5.9% olefin, 32.0% aromatic hydrocarbon (MVMA, 1987). Comparing the test fuels of this program to the national average, the summer test fuel had a lower olefinic fraction than the national average, and the winter test fuel lower paraffinic, and higher olefinic and aromatic fractions. However, most specifications were near or within the MVMA reported ranges of values. The winter test fuel had substantially higher olefin and aromatic fractions than the summer fuel providing a possibility for examination of emissions sensitivity to fuel composition.

Test facilities

A Horiba Model CDC800/DMA915 computerized DC electric chassis dynamometer was used to simulate vehicle road load. The dynamometer was enclosed in a temperature controlled chamber which permitted vehicle testing from −6.7°C (20°F) to 21.1°C (70°F). Vehicle tailpipe emissions were transferred through a heated line (110°C) to a Constant Volume Sampler (CVS) tunnel for dilution prior to sampling. Samples for analysis of regulated and unregulated emissions were obtained from this tunnel. The vehicle emissions sampling systems have been described in detail previously (Snow *et al.*, 1987).

Analytical procedures

Emissions characterization included THC, CO, NO_x, detailed HCs, and detailed aldehydes. THC, CO and NO_x measurements were completed using classical Flame Ionization Detector (FID), Non-Dispersive Infrared (NDIR), and Chemiluminescence procedures, respectively, as prescribed for federal emissions certification. Additionally, THC, CO and a number of physical parameters including engine exhaust temperature, speed, coolant and oil temperatures were measured with real-time or continuous data acquisition. The THC measurements were completed using both standard room temperature and hot (190.6°C) FID instrumentation.

Detailed HC measurements were completed using a gas chromatographic system with four analytical columns. Methane was measured with a 13 × molecular sieve column, the C_2–C_3 HCs with a type 58 silica gel column, 1,3-butadiene with a 0.19% picric acid column, and the C_4–C_{11} hydrocarbons with a Quadrex capillary column. The Quadrex column has been previously described for analysis of roadway HC samples (Stump and Dropkin, 1985). The previously described system was modified by replacing the cryogenic cold trap injection system with a 10 cm^3 Teflon coated stainless steel injection loop. This change was re-

Table 3. Test fuel specifications

Fuel property unleaded	National summer grade* average	Range	Commercial summer grade	National winter grade* average	Range	Commercial winter grade
RVP (kPa)†	71.7	(57.9–80.0)	79.3	93.1	(72.4–114.5)	86.9
Density (kg m^{-3})	‡		734	‡		731
Distillation Deg. F:						
Initial	‡		31.1	‡		30.0
10%	‡		53.9	‡		48.9
50%	‡		106.1	‡		105.0
90%	‡		161.1	‡		161.1
End point	‡		212.2	‡		191.1
Volume per cent						
Paraffins	59.8	(54.0–65.5)	61.9	62.1	(43.3–78.0)	41.7
Olefins	10.6	(7.3–16.1)	4.6	5.9	(2.2–16.6)	12.7
Aromatics	29.5	(25.7–33.3)	30.3	32.0	(17.1–47.5)	43.9
Unknowns	‡		3.2	‡		1.6
Benzene	‡		0.9	‡		0.9

*Source: MVMA (1987).
†RVP—Reid Vapor Pressure.
‡Data unavailable.

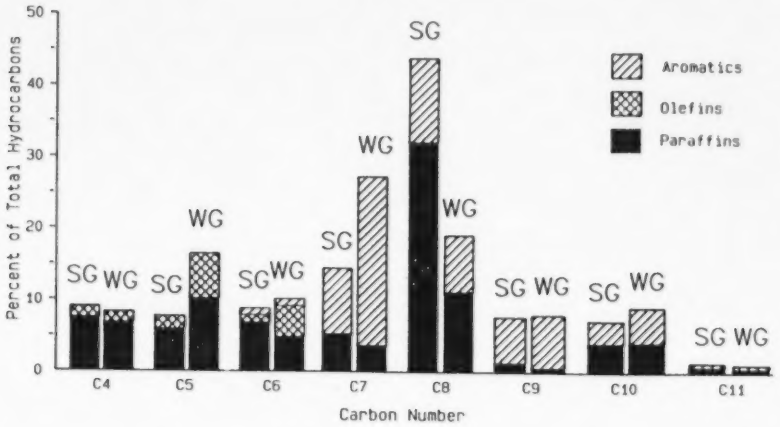

Fig. 1. Test fuel composition.

quired because of the higher concentrations typical of laboratory CVS samples compared to roadway samples. The exhaust does not achieve the same dilution in laboratory simulations as it does on actual roadways. The picric acid column was necessary for quantitative determination of 1,3-butadiene as this compound co-elutes with trans-2-butene on the Quadrex column.

Figure 2 illustrates the sample injection and analytical column configuration for all but the previously described Quadrex system. Valve 1 selects either of two Teflon coated stainless steel sample loops, depending upon desired analysis, one having a 1 cm^3 capacity and the other a 10 cm^3 capacity. The 1 cm^3 loop was used for methane analysis and 10 cm^3 loop for both the C_2–C_3 and 1,3-butadiene analyses. The valve 1 outlet was connected to valve 2 for selection of either the methane analytical column or routing to valve 3 for C_2–C_3 or 1,3-butadiene analysis. Separated HCs were routed from valve 3 to the instrument FID. The methane column consisted of 1.82 m × 3.18 mm stainless steel tubing packed with 80/100 Molecular Sieve 13×. Analysis was isothermal at 35°C with 30 cm^3 min^{-1} He carrier flow. Column conditions for C_2–C_3 analysis have been previously described (Black *et al.*, 1976). The 1,3-butadiene column consisted of 2 m × 2.13 mm stainless steel tubing packed with 0.19% Picric Acid on 80/100 mesh Graphpac-GC. This column was operated isothermal at 30°C with 30 cm^3 min^{-1} He carrier flow.

Detailed aldehyde measurements were completed using previously described 2,4-dinitrophenylhydrazine (DNPH) procedures (Tejada, 1986). These procedures use silica gel cartridges coated with acidified 2,4-DNPH to sample exhaust aldehydes and liquid chromatographic procedures for selective analysis of the individual compounds.

HC and aldehyde samples were collected and analyzed for each of the test phases of the FTP and MFTP. PC-AT/Lotus 1-2-3 based data processing procedures (Tejada and Sigsby 1988) were used to edit (assure correct compound identifications), and perform preliminary computations for each com-

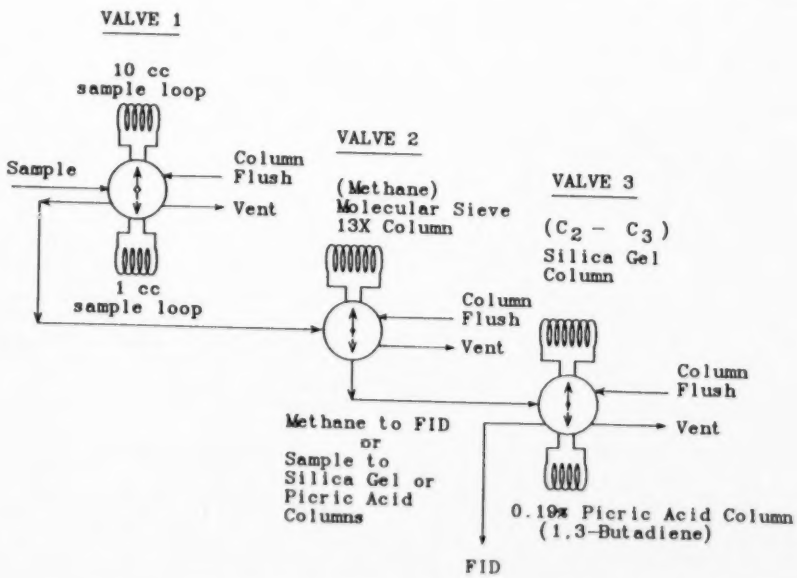

Fig. 2. Analytical system for methane, C_2–C_3, and 1,3-butadiene measurement.

pound (more than 200 compounds), followed by final g km^{-1} computations and archiving on IBM 9000 computing systems. The system 9000 also permitted varied compound summations for collective data presentation.

RESULTS AND DISCUSSION

HC emissions were examined using two variations of THC FID instrumentation, "cold" where the instrument and sample lines were operated at laboratory room temperature and "hot" where the instrument and sample lines were operated at 190.6°C (prescribed in the Federal Register for analysis of diesel THC). The emissions were also examined with column gas chromatography as previously described. Table 4 provides comparison of THC FID results with summations of gas chromatographic data. The hot and cold THC FID results were very similar, and on average about 5% less than the chromatographic compound summations. All THC data cited from this point will be based on summations of compounds analyzed with gas chromatography.

A composite of all emissions data for the 9-vehicle test fleet at each of the test conditions examined in this program is provided in Table 5. Results for individual vehicles are provided in Appendix A. Simple arithmetic mean values are provided along with relative standard deviations as an indication of vehicle to vehicle variability. This variability is vehicle-to-vehicle, not run-to-run as previously discussed. The data permit examination of the sensitivity of the emissions to ambient temperature, driving cycle and fuel composition. Emissions sensitivity to temperature can be examined by comparing 21.1°C SG-FTP and 4.4°C SG-FTP results, 4.4°C WG-FTP and −6.7° WG-FTP results, and 4.4°C WG-MFTP and −6.7°C WG-MFTP results. Driving cycle comparisons can be made between the FTP and MFTP schedules at 4.4°C with both SG and WG fuels, and at −6.7°C with WG fuel. No MFTP tests were completed at 21.1°C. Fuel composition effects can be examined at 4.4°C for both the FTP and MFTP driving schedules.

The data suggest statistically significant increases in THC and CO emissions for all of the test vehicles when the test temperature was decreased. NO_x emissions increased for seven vehicles and decreased for two vehicles when test temperature was decreased. This emission data base suggests that NO_x emissions are less sensitive to ambient temperature than THC and CO, and related more to individual vehicle emission control systems. Similar NO_x emission–temperature relationships were observed previously by Braddock (1981). Formaldehyde emissions did not appreciably change with test temperature decrease and the vehicle-to-vehicle variability was greater than observed with the other emissions. The composition of the HC emissions (in terms of weight per cent of THC) was not highly sensitive to temperature. There was a statistically significant increase in acetylene fraction with the SG fuel when the temperature was reduced from 21.1°C to 4.4°C, but this trend was not observed with the WG fuel on reduction from 4.4°C to −6.7°C.

The 4.4°C tests provided an opportunity to examine the sensitivity of the emissions to fuel composition. Although the emission rates (g km^{-1}) were not highly fuel sensitive, the THC composition was fuel sensitive. The paraffinic fraction of the exhaust gas reflected the fuel composition and was significantly higher with the SG fuel. Similarly, the aromatic fraction of the exhaust gas was significantly lower with the SG fuel. The olefinic fractions of the emissions, however, were not reflective of the fuel composition. The WG fuel had nearly 3 times the olefinic fraction of the SG fuel, but the emission fractions were similar with both fuels. Ethylene and propylene, which dominate the olefinic emissions, are not fuel components; these compounds typically result from fuel rich combustion of HC fuels. Benzene, also resulting from the combustion process was fuel dependent, with higher fractions resulting from the use of higher aromatic WG fuel.

Examination of FTP and MFTP data suggests that the preliminary idle period of the MFTP generally resulted in decreased CO emissions and elevated NO_x emissions. The impact of THC emission rates was not as clear. There were THC compositional trends noted, however. The acetylene fraction of THC was higher

Table 4. Total hydrocarbon method comparison

Test cycle	Temp. (°C)	Fuel	Total hydrocarbon ratio		
			Detailed/cold	Detailed/hot	Hot/cold
FTP	21.1	SG	1.04	1.00	1.04
FTP	4.4	SG	1.06	1.05	1.01
FTP	4.4	WG	1.07	1.02	1.04
MFTP	4.4	SG	1.00	1.12	0.89
MFTP	4.4	WG	1.05	1.04	1.01
MFTP	4.4	SG	1.10	1.08	1.01
FTP	−6.7	WG	1.09	1.07	1.02
		Average	1.06	1.05	1.00
		RSD	2.83	3.81	5.00

RSD—Relative Standard Deviation.

Table 5. Composite vehicle emissions

Temp (Deg. C)	21.1		4.4		4.4		4.4		4.4		−6.7		−6.7	
Test fuel	SG		SG		SG		WG		WG		WG		WG	
Test cycle	FTP		FTP		MFTP		FTP		MFTP		FTP		MFTP	
	Mean	RSD	Mean	RSD	Mean	RSD	Mean	RSD	Mean	RSD	Mean	RSD	Mean	RSD
THC (g km^{-1})	0.33	73.88	0.60	82.39	0.57	101.99	0.60	79.88	0.47	85.30	0.95	76.25	0.68	96.26
CO (g km^{-1})	3.96	56.10	7.62	48.12	6.70	47.99	8.83	37.97	6.25	38.36	12.07	39.72	8.84	60.72
NO_x (g km^{-1})	0.39	35.33	0.48	45.20	0.52	33.38	0.60	32.42	0.64	42.68	0.67	63.94	0.75	64.36
HCHO (mg km^{-1})	4.06	121.92	4.13	124.74	4.81	121.18	3.70	114.25	4.29	126.39	4.01	131.26	4.01	144.40
Oxygenates (mg km^{-1})	7.07	129.56	9.25	102.67	9.40	103.52	8.19	99.50	9.09	98.91	5.77	37.23	10.42	95.34
Paraffins (wt %) of total														
methane	15.39	31.93	13.02	24.88	14.85	32.98	12.34	26.52	14.21	22.46	9.52	25.69	11.47	24.65
isobutane	1.03	78.09	0.60	41.06	0.82	60.08	1.02	46.58	1.01	50.08	0.82	45.90	0.94	39.71
n-butane	4.81	48.37	3.92	25.19	4.49	43.69	3.45	35.93	3.58	39.55	2.88	44.23	3.26	35.59
isopentane	3.95	39.54	3.41	35.80	3.34	34.60	4.58	27.78	4.79	32.66	4.27	35.96	4.50	31.12
n-pentane	0.82	38.45	0.77	33.97	0.76	38.34	0.87	24.96	0.90	28.34	0.83	34.32	0.87	31.59
Total paraffins	51.97	15.01	49.37	12.55	51.44	11.85	40.33	10.90	42.26	8.65	36.41	15.14	38.62	11.69
Olefins (wt %) of total														
ethylene	4.54	31.55	5.03	18.60	5.98	21.05	4.76	14.74	5.40	22.80	4.43	13.91	5.17	30.80
propylene	2.34	43.07	2.24	33.95	2.67	52.32	1.78	31.19	2.14	42.60	1.43	24.91	1.80	27.30
Total olefins	12.62	21.24	13.05	19.15	14.93	25.31	13.53	9.98	14.24	17.99	12.80	11.94	13.97	15.73
Atomatics (wt %) of total														
benzene	4.61	94.92	3.51	41.13	3.34	49.00	4.82	33.06	4.50	28.83	4.36	32.45	4.48	30.84
toluene	9.91	19.92	10.40	17.27	8.84	19.37	17.30	6.30	16.42	9.36	18.63	7.59	18.39	10.65
p-xylene	1.48	40.55	1.46	21.97	1.25	21.67	1.26	19.48	1.12	17.28	1.43	24.48	1.24	20.37
m-xylene	3.67	37.56	3.64	19.98	3.16	20.70	3.06	18.24	2.82	15.31	3.47	24.16	3.01	19.85
o-xylene	1.85	45.03	1.82	21.68	1.58	20.30	1.52	19.34	1.38	14.77	1.71	25.66	1.45	19.76
Total aromatics	30.68	26.10	30.86	14.66	26.36	16.50	40.55	10.89	36.72	9.14	45.58	13.84	40.40	13.95
Acetylene (wt %)	2.95	90.17	4.35	36.22	5.48	82.90	4.30	44.88	5.77	76.96	3.61	31.26	5.76	70.28
Unknowns (wt %)	1.88	33.86	2.37	38.57	1.81	34.83	1.31	20.30	1.04	38.08	1.63	16.81	1.28	25.58

when the vehicles were operated over the MFTP driving schedule, the olefin fraction higher and the aromatic fraction lower.

There were no statistically significant trends in formaldehyde emissions rates noted with fuel, temperature or driving schedule. The average fleet formaldehyde emission rates were 3.07 to 4.81 mg km^{-1} for all conditions tested, but the vehicle-to-vehicle variability exceeded 100% of the mean for all conditions. 1,3-Butadiene emissions were determined in cold-start samples (idle-MFTP, Test phase 1-FTP). Table 6 provides results for each temperature–cycle–fuel condition examined. As a fraction of THC, little sensitivity to test conditions were noted. This compound constituted 0.07 to 0.13% of the THC for all conditions studied.

Most of the organic and CO emissions from these vehicles occurred during initial cold start operation. Figure 3 illustrates typical THC concentrations in the diluted exhaust as a function of time. The MFTP driving schedule begins at time 0 s with the preliminary 5 min idle followed by the first 505 s of UDDS transient driving (test phase 1); and the FTP schedule begins a time 300 s in the illustration. The temperature sensitivity of the THC emissions is easily observed. The integrated test phase THC emission rates were 0.58 g km^{-1} at 21.1°C and 3.24 g km^{-1} at −6.7°C. In this example, the −6.7°C MFTP integrated rate was 3.02 g km^{-1}, slightly lower than the FTP rate. In each case the emissions occurred while the catalyst was warming, and when the catalyst reached normal operating temperature the emissions were relatively insignificant.

Samples were collected during the initial 2 min, second 2 min, and final 1 min intervals of the −6.7°C idle period with the Nissan Sentra to examine how the HC composition changed during this transition of operating conditions. Results are summarized in Table 7. Acetylene and 1,3-butadiene emissions occurred entirely during the initial 2 min. The olefin emissions peaked as a fraction of THC during the second 2 min period, and the methane fraction was greatest in the final 1 min period. The aromatic fraction was lowest and benzene fraction highest during the final 1 min period. Aldehyde emissions were also examined during these tests. Formaldehyde emissions were 17.8 mg, 10.0 mg and 8.4 mg during the initial 2 min, second 2 min and final 1 min intervals, respectively; and constituted 29.1%, 35.6%, and 74.1% of total oxygenated organics, respectively.

Summarizing, HC and CO emission rates from the recent technology vehicles examined in this program increased significantly when ambient temperature was reduced from 21.1°C to −6.7°C. Formaldehyde emission rates were not highly temperature sensitive. The composition of the HC emissions did not vary significantly with temperature, but did vary with fuel composition. The fractional paraffin and aromatic characteristics of the emissions were reflective of the fuel. The olefinic fraction appeared to be less fuel sensitive. CO emissions were lower and NO_x emissions higher at reduced ambient temperatures if the engines were idled for 5 m prior to transient driving. THC emission rates were not sensitive to the preliminary idle, but the composition in terms of percentage of THC changed with higher acetylene and olefin fractions, and lower aromatic fractions typical of MFTP tests. Most of the organic and CO emissions occurred during the initial cold start operation of the vehicle. During cold start idle operation, acetylene and 1,3-butadiene were emitted entirely during the first 2 min.

Table 6. 1,3-Butadiene tailpipe emissions

	1,3-Butadiene, % of total hydrocarbons		
	Idle	Test phase 1	Test condition
Average (%)		0.10	70
RSD		111.41	SG
n =		9	FTP
THC*		0.85	
n =		9	
Average (%)		0.09	40
RSD		118.35	SG
n =		9	FTP
THC		2.35	
n =		9	
Average (%)	0.11		40
RSD	173.30		SG
n =	8		MFTP
THC	1.96	0.48	
n =	8	8	
Average (%)		0.07	40
RSD		132.48	WG
n =		8	FTP
THC		2.36	
n =		8	
Average (%)	0.13		40
RSD	154.41		WG
n =	8		MFTP
THC	1.54	0.45	
n =	8	8	
Average (%)		0.09	20
RSD		103.04	WG
n =		9	FTP
THC		5.79	
n =		9	
Average (%)	0.11		20
RSD	120.49		WG
n =	9		MFTP
THC	2.42	0.68	
n =	9	9	

*THC (g min^{-1}) (idle operation) and (g km^{-1}) transient operation).

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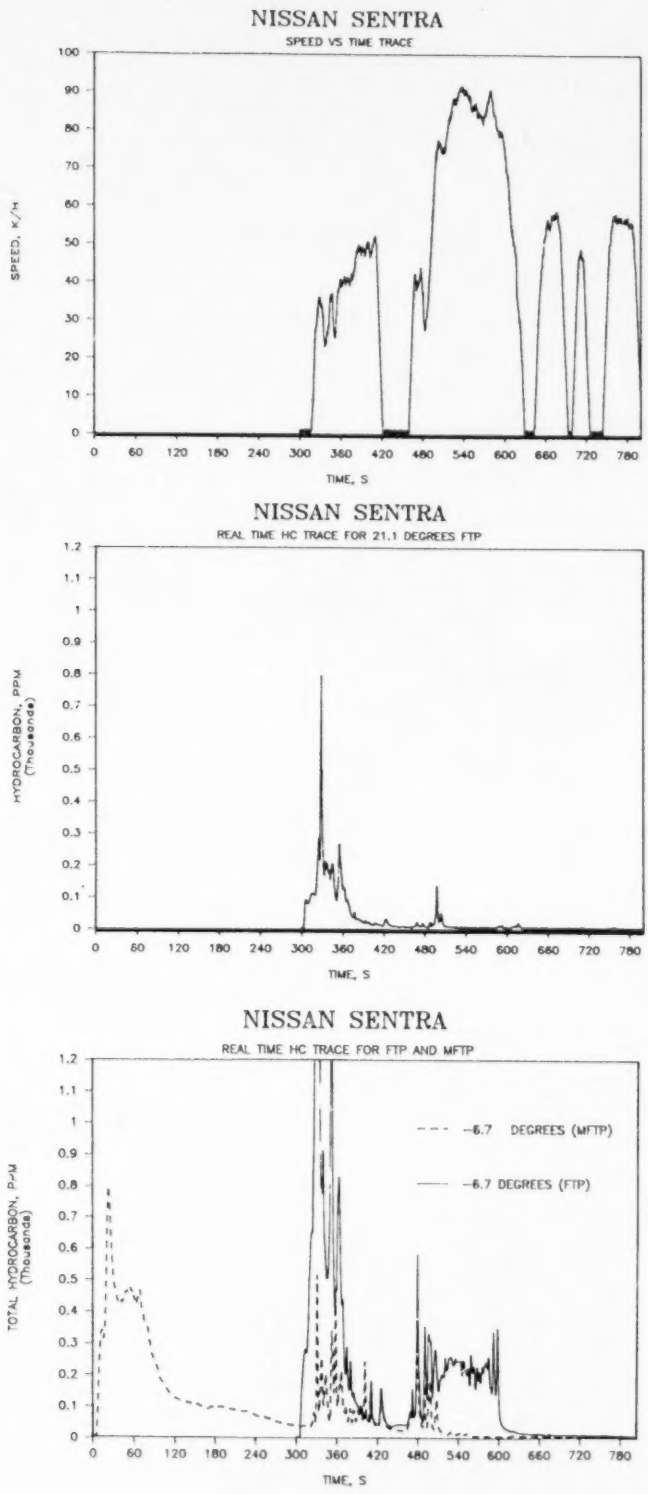

Fig. 3. THC emissions as a function of time.

Table 7. Nissan Sentra idle hydrocarbon emissions

Hydrocarbon compounds classes	Initial 2 min	Second 2 min	Final 1 min
Paraffins (%)	31.97	39.43	59.01
Olefins (%)	10.40	16.53	7.92
Aromatics (%)	40.22	43.28	32.53
Acetylenes (%)	15.42	0.00	0.00
Unknowns (%)	1.98	0.76	0.54
Methane (%)	7.68	7.89	17.38
Benzene (%)	3.28	3.82	5.94
Acetylene (%)	15.42	0.00	0.00
1,3-Butadiene (%)	0.12	0.00	0.00
NMHC (%)	92.32	92.11	82.62

REFERENCES

Ashby H. A., Stahman R. C., Eccleston B. H. and Hurn R. W. (1974) Vehicle emissions—summer to winter. SAE 741053. Society of Automotive Engineers, Inc., 400 Commonwealth Drive, Warrendale, PA.

Austin T. C., Rubenstein G. S., Verrelli L. D. and Moyer T. E. (1983) Light-duty vehicle CO emissions during cold weather. SAE 831698. Society of Automotive Engineers, Inc., 400 Commonwealth Drive, Warrendale, PA.

Baugh J., Ray W., Black F. and Snow R. (1987) Motor vehicle emissions under reduced ambient temperature idle operating conditions. *Atmospheric Environment* **21,** 2077.

Black F. M., High L. E. and Sigsby J. E. (1976) A gas chromatographic method for direct analysis of photochemically nonreactive hydrocarbons. *Chrom. Sci.* **14,** 257–260.

Braddock J. N. (1981) Impact of low ambient temperature on 3-way catalyst car emissions. SAE 810280. Society of Automotive Engineers, Inc., 400 Commonwealth Drive, Warrendale, PA.

Braddock J. N. (1982) Impact of low ambient temperature on diesel passenger car emissions. SAE 820278. Society of Automotive Engineers, Inc., 400 Commonwealth Drive, Warrendale, PA.

Carey P. M. (1987) Air toxics emissions from motor vehicles. EPA-AA-TSS-PA-86-5, EPA Office of Mobile Sources, Ann Arbor, MI.

DOT (1974) The sensitivity of projected aggregate fuel consumption to the conditions of individual fuel economy tests—part A. U.S. Department of Transportation, Transportation Systems Center, Cambridge, MA.

Eccleston B. H. and Hurn R. W. (1978) Ambient temperature and trip length—influence on automotive fuel economy and emissions. SAE 780613. Society of Automotive Engineers, Inc., 400 Commonwealth Drive, Warrendale, PA.

Gabele P., Karches W., Ray W. and Perry N. (1986) Emissions from a light-duty diesel: ambient temperature and fuel effects. SAE 860618. Society of Automotive Engineers, Inc., 400 Commonwealth Drive, Warrendale, PA.

Marshall W. F. and Eccleston B. H. (1980) Emissions at off-ambient temperatures. SAE 800512. Society of Automotive Engineers, Inc. 400 Commonwealth Drive, Warrendale, PA.

MVMA (1987) National gasoline survey. Motor Vehicle Manufacturers Association, 300 New Center Bldg., Detroit, MI.

Ostrouchov N. (1979) Effect of cold weather on motor vehicle emissions and fuel consumption—II. SAE 790229. Society of Automotive Engineers, Inc., 400 Commonwealth Drive, Warrendale, PA.

Snow R., Baker L., Crews W., Davis C. O., Duncan J., Perry N., Suidak P., Stump F., Ray W. and Braddock J. (1987) Characterization of emissions from a methanol fueled motor vehicle. In-review, JAPCA. Northrop Services, Inc., Research Triangle Park., N.C.

Spindt R. S. and Hutchins F. P. (1979) The effect of ambient temperature variation on emissions and fuel economy—an interim report. SAE 790228. Society of Automotive Engineers, Inc., 400 Commonwealth Drive, Warrendale, PA.

Stump F. D. and Dropkin D. L. (1985) Gas chromatographic method for quantitative determination of C_2 to C_{13} hydrocarbons in roadway vehicle emissions. *Analyt. Chem.* **57,** 2629–2634.

Tejada S. B. (1986) Evaluation of silica gel cartridges coated *in situ* with acidified 2,4-dinitrophenyl-hydrazine for sampling aldehydes and ketones in air. *Int. J. Envir. Analyt. Chem.* **26,** 167–185.

Tejada S. B. and Sigsby J. E. (1988) Identification of chromatographic peaks using Lotus 1-2-3. *J. chromat. Sci.* (submitted).

U.S. Code of Federal Regulations (1983) Title 40, Part 86-Control of air pollution from new motor vehicles and new motor vehicle engines; certification and test procedures.

USEPA (1987) Air quality benefits of alternative fuels. U.S. Environmental Protection Agency, Office of Mobile Sources, Ann Arbor, MI.

APPENDIX A

Individual vehicle emissions are reported in Tables A1–A9.

Table A1. 1987 Toyota Camry
Vehicle test conditions

Temp (°C)	21.1	4.4	4.4	4.4	4.4	−6.7	−6.7
Test fuel	SG	SG	SG	WG	WG	WG	WG
Test cycle	FTP	FTP	MFTP	FTP	MFTP	FTP	MFTP
THC (g km^{-1})	0.21	0.26	•	•	•	0.37	0.24
CO (g km^{-1})	1.24	2.75	•	•	•	4.47	0.79
NO_x (g km^{-1})	0.12	0.11	•	•	•	0.09	0.07
HCHO (mg km^{-1})	1.49	1.11	•	•	•	1.98	0.87
Oxygenates (mg km^{-1})	2.73	2.03	•	•	•	4.74	1.96
Paraffins (wt %) of total							
methane	7.31	11.47	•	•	•	8.82	10.82
isobutane	0.53	0.29	•	•	•	0.41	0.66
n-butane	2.00	3.42	•	•	•	1.17	1.84

Table A1. (*Contd.*)

Temp (°C)	21.1	4.4	4.4	4.4	4.4	−6.7	−6.7
Test fuel	SG	SG	SG	WG	WG	WG	WG
Test cycle	FTP	FTP	MFTP	FTP	MFTP	FTP	MFTP
isopentane	3.93	3.78	•	•	•	1.81	2.89
n-pentane	0.74	0.77	•	•	•	0.35	0.54
Total paraffins	37.38	39.78	•	•	•	27.32	32.53
Olefins (wt %) of total							
ethylene	3.02	5.31	•	•	•	4.13	4.60
propylene	1.83	2.92	•	•	•	1.42	2.45
Total olefins	10.60	15.94	•	•	•	10.42	12.76
Aromatics (wt %) of total							
benzene	1.50	4.03	•	•	•	3.13	3.89
toluene	8.60	10.29	•	•	•	16.30	20.88
p-xylene	2.82	1.99	•	•	•	2.20	1.65
m-xylene	6.72	4.68	•	•	•	5.32	3.85
o-xylene	3.71	2.46	•	•	•	2.69	1.81
Total aromatics	47.37	36.66	•	•	•	56.26	48.26
Acetylene (wt %)	2.79	5.75	•	•	•	4.01	4.78
Unknowns (wt %)	1.87	1.89	•	•	•	2.04	1.70

Table A2. 1986 General Motors Grand Am
Vehicle test conditions

Temp (°C)	21.1	4.4	4.4	4.4	4.4	−6.7	−6.7
Test fuel	SG	SG	SG	WG	WG	WG	WG
Test cycle	FTP	FTP	MFTP	FTP	MFTP	FTP	MFTP
THC (g km^{-1})	0.14	0.23	0.19	0.20	0.15	0.47	0.20
CO (g km^{-1})	1.32	3.03	1.93	3.33	2.43	6.25	3.56
NO_x (g km^{-1})	0.22	0.25	0.24	0.50	0.29	0.37	0.29
HCHO (mg km^{-1})	2.34	2.65	3.33	3.19	3.44	6.63	3.60
Oxygenates (mg km^{-1})	3.96	7.17	6.35	5.84	9.66	9.69	9.63
Paraffins (wt %) of total							
methane	17.88	16.64	21.67	17.56	18.07	9.48	11.32
isobutane	0.38	0.69	0.99	0.90	1.06	0.66	0.96
n-butane	3.14	4.68	5.64	3.43	4.41	1.83	3.11
isopentane	3.83	3.23	3.23	4.29	4.55	4.11	4.23
n-pentane	0.69	0.67	0.68	0.74	0.75	0.78	0.78
Total paraffins	46.99	58.70	58.38	43.34	45.37	32.19	36.41
Olefins (wt %) of total							
ethylene	5.29	5.01	6.46	5.63	7.04	3.55	5.52
propylene	2.94	2.49	4.10	2.31	3.23	0.99	2.23
Total olefins	14.75	13.63	17.15	14.74	18.40	10.57	13.32
Aromatics (wt %) of total							
benzene	3.18	2.93	2.99	4.93	5.55	2.92	3.88
toluene	10.22	6.21	7.28	15.48	14.88	18.69	20.44
p-xylene	1.87	1.32	0.97	1.17	0.95	1.55	1.42
m-xylene	4.56	3.26	2.61	2.81	2.44	3.74	3.59
o-xylene	2.32	1.64	1.28	1.41	1.26	1.90	1.68
Total aromatics	35.12	22.59	20.63	37.14	32.70	51.65	45.11
Acetylene (wt %)	1.24	2.97	2.23	3.56	2.81	3.72	4.06
Unknowns (wt %)	2.08	1.99	1.67	1.22	0.74	1.90	1.12

Table A3. 1986 Ford Mustang
Vehicle test conditions

Temp (°C)	21.1	4.4	4.4	4.4	4.4	−6.7	−6.7
Test fuel	SG	SG	SG	WG	WG	WG	WG
Test cycle	FTP	FTP	MFTP	FTP	MFTP	FTP	MFTP
THC (g km^{-1})	0.78	1.67	0.73	1.52	0.65	1.93	0.96
CO (g km^{-1})	3.99	10.94	5.71	11.21	3.90	15.38	5.98

Table A3. (*Contd.*)

Temp (°C)	21.1	4.4	4.4	4.4	4.4	−6.7	−6.7
Test fuel	SG	SG	SG	WG	WG	WG	WG
Test cycle	FTP	FTP	MFTP	FTP	MFTP	FTP	MFTP
NO_x (g km^{-1})	0.55	0.80	0.78	0.90	1.12	1.09	1.31
HCHO (mg km^{-1})	15.55	17.05	18.79	13.68	16.38	16.23	18.15
Oxygenates (mg km^{-1})	27.67	32.39	32.81	27.64	28.91	•	34.01
Paraffins (wt %) of total							
methane	10.13	8.45	10.30	7.74	10.43	6.95	8.21
isobutane	1.15	0.77	1.18	1.37	1.99	1.31	1.64
n-butane	7.25	5.10	7.13	3.74	6.08	4.40	5.38
isopentane	4.51	3.63	4.53	5.71	7.22	5.66	6.95
n-pentane	1.13	0.95	1.10	1.14	1.37	1.08	1.38
Total paraffins	59.70	53.77	58.49	41.20	45.58	39.26	43.70
Olefins (wt %) of total							
ethylene	5.16	4.25	5.91	4.00	4.80	3.80	4.00
propylene	3.16	1.47	2.39	1.17	1.31	1.14	1.36
Total olefins	12.90	10.37	12.69	12.34	11.20	12.71	13.24
Aromatics (wt %) of total							
benzene	1.74	2.11	1.83	3.14	3.04	3.36	3.40
toluene	7.17	9.65	8.56	18.42	16.02	18.72	19.28
p-xylene	1.28	1.51	1.25	1.29	1.23	1.30	1.17
m-xylene	3.30	3.83	3.17	3.18	2.96	3.17	2.86
o-xylene	1.63	1.89	1.57	1.55	1.49	1.54	1.39
Total aromatics	23.29	29.41	25.31	40.42	41.04	41.63	40.50
Acetylene (wt %)	2.11	3.94	1.37	4.67	1.37	4.87	1.39
Unknowns (wt %)	2.00	2.53	2.14	1.36	0.82	1.59	1.20

Table A4. 1984 General Motors Cavalier
Vehicle test conditions

Temp (°C)	21.1	4.4	4.4	4.4	4.4	−6.7	−6.7
Test fuel	SG	SG	SG	WG	WG	WG	WG
Test cycle	FTP	FTP	MFTP	FTP	MFTP	FTP	MFTP
THC (g km^{-1})	0.24	0.28	0.30	0.36	0.30	0.68	0.44
CO (g km^{-1})	6.07	8.01	3.88	9.67	6.91	14.86	17.95
NO_x (g km^{-1})	0.46	0.39	0.37	0.35	0.30	0.36	0.44
HCHO (mg km^{-1})	•	1.73	3.02	2.27	3.44	1.49	3.07
Oxygenates (mg km^{-1})	•	4.33	5.84	6.19	6.34	4.29	8.56
Paraffins (wt %) of total							
methane	12.19	15.69	14.20	13.92	14.52	9.39	13.04
isobutane	1.78	1.12	0.61	1.95	1.47	1.47	1.29
n-butane	6.40	5.16	3.49	5.90	4.99	5.01	4.42
isopentane	7.53	6.27	5.54	6.41	6.65	6.82	5.85
n-pentane	1.47	1.32	1.28	1.11	1.14	1.28	1.09
Total paraffins	53.02	51.02	48.13	46.78	45.48	43.77	43.11
Olefins (wt %) of total							
ethylene	6.72	7.10	7.64	5.91	6.60	5.32	9.27
propylene	1.63	1.69	2.49	1.64	2.04	1.36	2.01
Total olefins	14.03	14.88	17.57	14.76	15.88	14.03	19.04
Aromatics (wt %) of total							
benzene	9.24	6.92	6.88	7.73	6.59	6.52	7.45
toluene	12.18	11.76	11.99	16.67	17.29	18.87	16.20
p-xylene	0.83	0.96	0.93	0.85	0.89	0.98	0.87
m-xylene	2.17	2.39	2.41	2.17	2.43	2.45	2.10
o-xylene	1.08	1.20	1.17	1.06	1.15	1.20	0.99
Total aromatics	31.70	30.34	30.86	35.31	35.72	38.82	33.93
Acetylene (wt %)	0.58	3.09	2.75	2.42	2.38	2.11	3.08
Unknowns (wt %)	0.67	0.69	0.71	0.73	0.55	1.28	0.86

Table A5. 1986 Chrysler Omni
Vehicle test conditions

Temp (°C)	21.1	4.4	4.4	4.4	4.4	−6.7	−6.7
Test fuel	SG	SG	SG	WG	WG	WG	WG
Test cycle	FTP	FTP	MFTP	FTP	MFTP	FTP	MFTP
THC (g km^{-1})	0.72	1.16	1.94	1.19	1.40	2.44	2.32
CO (g km^{-1})	4.93	7.52	9.71	9.64	8.83	15.00	11.29
NO_x (g km^{-1})	0.42	0.54	0.57	0.79	0.80	0.85	1.05
HCHO (mg km^{-1})	5.85	6.54	6.02	4.88	*	*	*
Oxygenates (mg km^{-1})	*	14.89	11.29	9.92	*	*	*
Paraffins (wt %)							
of total							
methane	14.32	10.67	8.26	10.40	9.21	7.93	8.08
isobutane	0.70	0.58	0.68	1.24	1.01	1.06	1.18
n-butane	4.19	4.13	4.40	4.04	3.31	3.34	3.88
isopentane	2.75	2.80	3.12	5.67	5.70	5.47	5.86
n-pentane	0.58	0.61	0.69	1.05	1.03	1.07	1.12
Total paraffins	54.96	52.99	56.06	41.56	40.90	39.23	39.90
Olefins (wt %)							
of total							
ethylene	3.13	3.76	3.29	3.95	3.15	4.36	4.75
propylene	1.11	1.47	1.02	1.34	0.73	1.13	0.86
Total olefins	7.05	9.54	8.79	13.23	11.91	14.82	14.91
Aromatics (wt %)							
of total							
benzene	1.66	2.05	1.65	2.59	2.58	2.86	2.61
toluene	10.45	10.17	7.74	17.71	18.66	19.57	18.68
p-xylene	1.27	1.34	1.49	1.07	1.03	1.12	1.09
m-xylene	3.23	3.41	3.74	2.61	2.72	2.71	2.64
o-xylene	1.60	1.61	1.83	1.25	1.30	1.28	1.25
Total aromatics	26.23	26.99	26.08	36.35	36.91	38.93	36.95
Acetylene (wt %)	9.61	6.54	6.28	7.41	8.80	5.41	6.46
Unknowns (wt %)	2.56	3.97	2.81	1.46	1.59	1.67	1.79

Table A6. 1987 Nissan Sentra
Vehicle test conditions

Temp (°C)	21.1	4.4	4.4	4.4	4.4	−6.7	−6.7
Test fuel	SG	SG	SG	WG	WG	WG	WG
Test cycle	FTP	FTP	MFTP	FTP	MFTP	FTP	MFTP
THC (g km^{-1})	0.15	0.31	0.35	0.29	0.30	0.51	0.41
CO (g km^{-1})	2.13	6.30	6.48	6.66	5.63	9.86	7.46
NO_x (g km^{-1})	0.50	0.52	0.57	0.61	0.66	0.85	0.89
HCHO (mg km^{-1})	3.88	3.53	1.93	1.64	2.14	1.39	1.37
Oxygenates (mg km^{-1})	5.61	6.69	3.65	4.05	5.48	3.17	4.13
Paraffins (wt %)							
of total							
methane	21.61	16.31	14.42	13.30	13.58	10.44	13.75
isobutane	2.82	0.51	1.81	0.82	0.72	0.69	0.89
n-butane	9.20	3.49	7.02	2.85	2.53	2.51	2.85
isopentane	4.40	3.13	3.07	4.26	4.11	3.69	3.63
n-pentane	0.70	0.72	0.55	0.80	0.83	0.69	0.69
Total paraffins	63.12	49.84	48.94	38.33	37.67	34.57	36.47
Olefins (wt %)							
of total							
ethylene	2.84	4.94	5.61	4.55	5.36	4.83	4.85
propylene	1.57	2.32	2.76	1.82	2.05	1.79	1.83
Total olefins	12.51	13.08	16.52	13.06	14.40	13.49	13.35
Aromatics (wt %)							
of total							
benzene	2.14	3.55	2.64	5.43	4.23	5.72	5.10
toluene	7.55	10.92	6.75	17.79	17.08	19.48	16.72
p-xylene	0.91	1.44	1.16	1.34	1.08	1.46	1.16
m-xylene	2.32	3.62	2.86	3.24	2.76	3.54	2.74
o-xylene	0.84	1.80	1.37	1.64	1.32	1.75	1.34
Total aromatics	19.83	31.14	21.81	43.53	36.62	47.54	37.29
Acetylene (wt %)	2.96	3.68	11.26	3.87	10.33	2.87	11.91
Unknowns (wt %)	1.59	2.24	1.48	1.22	0.99	1.55	0.99

Table A7. 1985 Honda Accord
Vehicle test conditions

Temp (°C)	21.1	4.4	4.4	4.4	4.4	−6.7	−6.7
Test fuel	SG	SG	SG	WG	WG	WG	WG
Test cycle	FTP	FTP	MFTP	FTP	MFTP	FTP	MFTP
THC (g km^{-1})	0.21	0.58	0.41	0.45	0.29	0.86	0.61
CO (g km^{-1})	5.90	12.29	11.45	12.45	9.02	17.83	14.93
NO_x (g km^{-1})	0.35	0.39	0.40	0.45	0.60	0.47	0.58
HCHO (mg km^{-1})	1.05	2.29	1.52	1.51	1.20	1.86	2.36
Oxygenates (mg km^{-1})	2.57	8.61	5.30	3.75	2.97	7.22	7.94
Paraffins (wt %) of total							
methane	19.49	8.89	11.50	8.94	14.74	6.90	8.57
isobutane	0.62	0.40	0.39	0.49	0.52	0.43	0.48
n-butane	3.39	2.41	1.71	1.91	2.38	1.83	2.22
isopentane	2.12	1.98	2.00	2.54	2.92	2.85	3.25
n-pentane	0.43	0.44	0.43	0.54	0.66	0.60	0.65
Total paraffins	48.12	40.16	40.60	31.63	37.06	30.49	32.12
Olefins (wt %) of total							
ethylene	5.82	5.36	6.71	4.91	5.64	4.04	4.72
propylene	4.14	3.79	4.79	2.80	3.16	2.05	2.13
Total olefins	16.54	16.67	20.58	14.87	15.43	13.95	14.92
Aromatics (wt %) of total							
benzene	3.48	2.96	3.18	4.06	4.21	3.97	4.34
toluene	10.07	12.06	9.69	18.79	17.72	20.97	20.41
p-xylene	1.58	1.93	1.74	1.70	1.47	1.62	1.55
m-xylene	3.88	4.74	4.39	4.08	3.65	3.96	3.74
o-xylene	2.01	2.40	2.17	2.05	1.75	1.91	1.85
Total aromatics	31.46	37.39	33.35	48.87	42.24	51.25	48.81
Acetylene (wt %)	2.37	3.49	3.26	3.07	4.15	2.89	2.67
Unknowns (wt %)	1.73	2.30	2.22	1.58	1.12	1.42	1.48

Table A8. 1987 Toyota Corolla
Vehicle test conditions

Temp (°C)	21.1	4.4	4.4	4.4	4.4	−6.7	−6.7
Test fuel	SG	SG	SG	WG	WG	WG	WG
Test cycle	FTP	FTP	MFTP	FTP	MFTP	FTP	MFTP
THC (g km^{-1})	0.27	0.38	0.28	0.34	0.34	0.59	0.47
CO (g km^{-1})	2.75	5.34	5.17	5.39	5.12	8.84	7.91
NO_x (g km^{-1})	0.44	0.69	0.67	0.75	0.80	1.48	1.52
HCHO (mg km^{-1})	0.75	0.66	2 34	1.30	2.43	1.30	1.47
Oxygenates (mg km^{-1})	2.38	2.56	5.07	2.96	6.30	5.32	10.35
Paraffins (wt %) of total							
methane	14.76	15.63	21.11	15.08	18.19	14.86	16.17
isobutane	0.40	0.41	0.43	0.59	0.59	0.61	0.59
n-butane	3.29	2.71	2.83	2.20	2.27	2.34	2.16
isopentane	2.77	2.39	2.42	3.55	3.36	3.56	3.48
n-pentane	0.69	0.55	0.57	0.69	0.64	0.71	0.68
Total paraffins	47.72	47.06	49.01	38.84	40.62	39.45	39.65
Olefins (wt %) of total							
ethylene	3.42	4.48	5.82	4.54	4.60	5.22	4.56
propylene	1.63	1.77	0.66	1.29	1.64	1.26	1.49
Total olefins	12.16	10.78	11.65	11.10	11.32	12.07	11.30
Aromatics (wt %) of total							
benzene	3.31	3.64	3.60	5.41	4.98	5.84	5.28
toluene	12.99	12.05	8.56	16.99	15.68	18.26	16.11
p-xylene	1.54	1.27	1.11	1.32	1.02	1.32	1.03
m-xylene	3.92	3.29	2.76	3.18	2.43	3.13	2.55
o-xylene	1.93	1.63	1.58	1.58	1.21	1.54	1.24
Total aromatics	33.78	32.07	24.33	41.77	33.85	42.94	35.13
Acetylene (wt %)	3.48	6.82	13.56	6.96	13.37	4.24	12.94
Unknowns (wt %)	2.86	3.31	1.45	1.34	0.84	1.32	1.00

Table A9. 1987 Dodge Caravelle
Vehicle test conditions

Temp (°C)	21.1	4.4	4.4	4.4	4.4	−6.7	−6.7
Test fuel	SG	SG	SG	WG	WG	WG	WG
Test cycle	FTP	FTP	MFTP	FTP	MFTP	FTP	MFTP
THC (g km^{-1})	0.25	0.53	0.33	0.46	0.34	0.70	0.47
CO (g km^{-1})	7.29	12.41	9.30	12.25	8.18	16.11	9.68
NO_x (g km^{-1})	0.41	0.60	0.57	0.45	0.58	0.51	0.56
HCHO (mg km^{-1})	1.54	1.59	1.55	1.10	0.98	1.16	1.21
Oxygenates (mg km^{-1})	4.57	4.58	4.89	5.13	3.98	5.96	6.78
Paraffins (wt %) of total							
methane	20.55	13.41	17.35	11.78	14.92	10.94	13.27
isobutane	0.87	0.67	0.44	0.83	0.69	0.74	0.77
n-butane	4.34	4.19	3.66	3.50	2.69	3.46	3.49
isopentane	3.65	3.51	2.79	4.23	3.84	4.44	4.39
n-pentane	0.90	0.90	0.74	0.85	0.80	0.90	0.92
Total paraffins	56.70	50.97	51.90	40.94	45.38	41.39	43.66
Olefins (wt %) of total							
ethylene	5.39	5.06	6.37	4.61	5.99	4.65	4.27
propylene	3.01	2.28	3.12	1.86	2.93	1.75	1.87
Total olefins	13.04	12.60	14.50	14.12	15.38	13.10	12.87
Aromatics (wt %) of total							
benzene	4.19	3.39	3.95	5.30	4.80	4.93	4.35
toluene	9.77	10.46	10.15	16.51	14.06	16.82	16.79
p-xylene	1.19	1.41	1.31	1.31	1.28	1.33	1.23
m-xylene	2.90	3.52	3.31	3.20	3.19	3.22	2.98
o-xylene	1.51	1.78	1.66	1.60	1.57	1.62	1.49
Total aromatics	27.31	31.14	28.48	41.02	34.65	41.23	37.58
Acetylene (wt %)	1.39	2.88	3.15	2.45	2.94	2.39	4.54
Unknowns (wt %)	1.55	2.42	1.97	1.50	1.64	1.93	1.38